



January – March 2018

Special Issue: International Symposium on Food Security and Sustainable Development
November 23-24, 2017, HCM City, Vietnam

Theme: Food Security

Research

Analysis of joule heating of pork sausages

László Baranyai¹, Luigi De Vivo², Márton Magnucz³,
Eszter Vozáry⁴, Francesco Marra⁵

¹Department of Physics and Control, Szent István University,
Somlói u. 14-16., Budapest, H-1118, Hungary.

²Department of Industrial Engineering, University of Salerno,
via Giovanni Paolo II, 132, 84084 Fisciano, SA, Italy.

³Department of Physics and Control, Szent István University,
Somlói u. 14-16., Budapest, H-1118, Hungary.

⁴Department of Physics and Control, Szent István University, Somlói u. 14-16., Budapest, H-1118, Hungary.

⁵Department of Industrial Engineering, University of Salerno, via Giovanni Paolo II, 132, 84084 Fisciano, SA,
Italy.

***Corresponding author's email address:** Baranyai.Laszlo@etk.szie.hu

Received: November 22, 2017/ Accepted: August 16, 2018/ Published online: September 1, 2018

Academic Editor: Dam Sao Mai

To cite this article:

Baranyai, L., De Vivo, L., Magnucz, M., Vozáry, F. and Marra, F. (2018). Analysis of joule heating of pork sausages.
Asia-Pacific Journal of Food Safety and Security, 4(1), 10-20.

Highlights

- Joule heating is suitable for cooking using electricity without transfer medium.
- Cold point of foodstuff is at different location compared to traditional heat treatment.
- Joule heating needs new calculations to reach sufficient treatment for food safety.



About Authors

László Baranyai (PhD) is Associate Professor at Szent Istvan University, Faculty of Food Science. He is food engineer. His research interests are in machine vision systems of agriculture and application of lasers for quality assessment.

Luigi De Vivo (MSc) is chemical and food engineer, graduated at University of Salerno (Italy) and Szent István University (Hungary). Presently he is working at Ferrero in Italy.

Márton Magnucz (BSc) is master student at Szent Istvan University, Faculty of Food Science. He is interested in physics and in the analysis of meat products.

Eszter Vozáry (CSc) is retired Associate Professor of Szent István University, Faculty of Food Science. Her research interests are in food physics, rheology and dielectric properties of food.

Francesco Marra (PhD) is Assistant Professor at University of Salerno. He is chemical engineer. His research interests are transport phenomena, microwave heating, radio-frequency heating, virtualization of food processes.

Abstract

Joule heating, also called as ohmic heating, is a promising technology for cooking. It is expected to be rapid and economic since no transfer medium is required, electrical energy is directly affecting food-stuff. Additionally, cooking is induced by current stream and starts inside food. This reverse direction compared to the traditional technique needs different considerations, such as cold point calculation and expected final surface temperature. Viennese type smoked pork sausages were acquired in retail. Adjustable AC power supply of 0-240 V (1000 VA, 50 Hz) was applied to control current and voltage. Infrared thermometer was used to record temperature data at three positions along the sample surface. Thermal images were captured during cooking with the spectral range of 8-14 μm . Both infrared thermometer and thermovision camera had the same accuracy of $\pm 2\%$. Two parallel samples were cooked during experiments. Measurements were performed in 3 replicates. Three levels of voltage were applied (50 V, 125 V and 200 V). Low level was considered inefficient and too slow, while high level did burn meat around electrode easily. Kinetics of current and surface temperature were analyzed and compared. Based on the temperature change, optimal cooking protocol can be suggested in order to warm up quickly and cook safe food without burning and decreasing its value. Finite element calculations were performed using software COMSOL Multiphysics®. According to the results, Joule heating treatment is an effective way of cooking and easy to control. In spite of the fact that technique is investigated from different aspects, there are still open questions and issues before deployment into everyday practice.

Keywords: ohmic cooking; thermal imaging; finite element simulation

Introduction

Food industry often needs energy to generate steam or hot water in order to perform common technology processes, such as cooking, pasteurization, distillation. Ohmic heating is a promising alternative providing economic and short time treatment (Sakr & Liu, 2014). It was observed to be successful primarily for liquid foods, such as beer (0.143 S/m), apple juice (0.239 S/m), tomato juice (1.697 S/m). The procedure was generally observed to be efficient for materials with conductivity in the range of 0.1 – 10 S/m (Jaeger et al., 2016). Compared with other techniques, ohmic heating obtained higher energy efficiency in the range of 82-97%, while microwave heating reached lower level of up to 65% (Castro et al., 2004; Jones et al., 2002). Only electric current heated resistors were able to transfer energy with similar effectiveness. The biggest advantage of ohmic cooking is the shorter treatment time (Sakr & Liu, 2014). The frequency of applied alternate current is mostly in the range of 50 – 60 Hz. The parameter frequency affected procedure as increased frequency from 50 Hz to 10,000 Hz resulted in longer treatment regarding time required to reach target temperature (Lima & Sastry, 1999). Foodstuff subjected to ohmic cooking are typically liquids or homogeneous pulps. In most cases, additional salt is used to improve electric conductivity. Ground beef of adjusted fat levels of 2, 9 and 15% were processed with ohmic heating (Bozkurt & Icier, 2010). Beef samples were heated up to 70 °C with gradient of 20 – 40 V/cm. Cooking time was significantly less (below 96 s) compared to traditional method (above 356 s). Significant difference was observed in volume reduction as ohmic heating resulted in the range of 5.36 – 6.97% while traditional method obtained 26.01 – 31.59%. Other parameters were similar on final products, such as cooking yield. In another experiment, beef muscle emulsion was injected with 3% salt solution during pretreatment (Zell et al., 2010). Samples were inoculated with *L. innocua* 11288 and microbial analysis was performed to test the effect of ohmic heating. The electricity source of 100 V was applied until samples reached target temperature of 72 °C or 95 °C. The comparison of cooking protocols revealed that low temperature long time (10 – 12.5 min) treatment reached lower inactivation values (\log_{10} CFU/g). On the other hand, high temperature short time treatment eliminated test microorganism but resulted in higher cook loss, therefore authors suggested middle level procedure for safety and optimal quality. Cooking time was decreased 7 – 15 fold depending on the applied protocol. Whole beef muscles soaked in salt solution obtained similar results (Zell et al., 2009), but authors suggested that special attention should be paid to brining in order to reach even salt distribution. Ohmic cooking was successfully used to prepare meat balls (Sengun et al., 2014). The total mesophilic aerobic bacteria number decreased significantly, yeast and mould fall to undetectable levels using 15.46 V/cm voltage gradient. Since ohmic heating did not eliminate *Listeria monocytogenes* from meat ball samples, authors suggest application of this technology in combination with other methods. In case of dairy products, it was concluded as summary of literature that alternate

current of 50 – 60 Hz can decrease thermal resistance of microorganisms (Cappato et al., 2017). The hazard of non-uniform treatment was highlighted as extreme hot regions result in decreased quality due to over processing but cold spots are critical from food safety aspects. Low fat dairy products ($\leq 3\%$) were observed to reach higher microbial inactivation rates. Cappato et al. (2017) concluded that reported non-thermal effect of ohmic heating depends on the strain, culture medium and process conditions. Additionally, food structure, especially non-conductive substances promote non-uniform heat generation. Number of studies investigating ohmic heating of foodstuff like sausages is limited and reported results are mainly product specific.

The main goal of presented study was to evaluate effect of ohmic heating parameters on cooking of pork sausages. It was also objective to compare experimental data to simulation results in order to help optimization.

Materials and methods

Materials

Viennese type smoked pork sausages were acquired in retail store. The packages of 160 g consisted of 6 pieces with the geometry of $\varnothing 2.8$ cm diameter and 17 cm length. Measurements were performed with two pieces in parallel and three replicates. According to the assumed salt content of sausages, three simulations were performed. Average salt content of the product was 2.5%, but changes can occur due to treatment and immersion into NaCl solution. Adjusted properties are listed in the following table (Table 1.)

Table 1. Properties of sausages used in simulation

Property	Low	Medium	High
Salt content, %	1.25	2.50	5.00
Electric conductivity, S/m	1.50	2.79	5.11
Density, kg/m ³	1023	1031	1048
Specific heat, J/kgK	3279	3239	3160

Parameter estimations are based on Choi et al. (1986).

Methods

Adjustable power supply (model TD 1001, TRAKIS) of 230/0-240 V and 1000 VA was applied to provide required electricity. Multimeters measured voltage (VC2020, Voltcraft, Germany) and current (MY-64, Mastech, China). Electric circuit is introduced in the following figure (Fig. 1). Three voltage levels were adjusted as 50, 125 and 200 V resulting in 3.33, 8.33 and 13.33 V/cm gradient. Surface

temperature was monitored on three locations using an infrared thermometer of $\pm 2\%$ accuracy (GM320, Benetech, China).

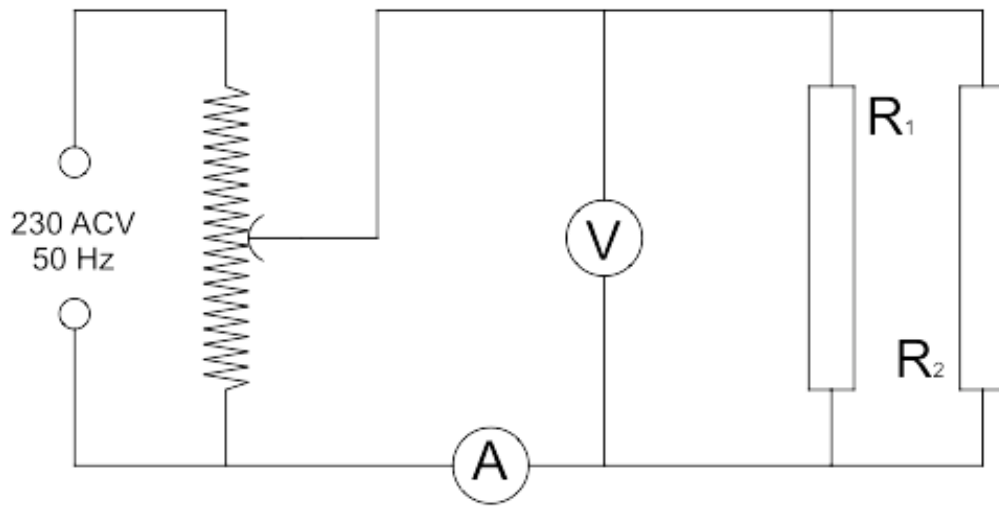


Figure 1. Electric circuit of the measurement.

Samples are represented by resistances R_1 and R_2

The vision system consisted of a thermal imaging instrument (MobIR®M4, Wuhan Guide Infrared Technology Co., China) operating in the spectral range of 8-14 μm with $\pm 2\%$ accuracy. Captured data were evaluated using bundled IR Analyzer software (Wuhan Guide Infrared Technology Co., China). Besides still image acquisition, USB video grabber (MT4169, Media-Tech) was used to capture video of the treatment and read temperature values more frequently.

Magnitude and phase angle of electrical impedance of sausages were measured with a HP4284A and a HP4285A precision LCR meters in frequency range of 30 Hz – 30 MHz. The measurement was performed in three replicates. Two Ag/AgCl electrodes (RC2, WPI Inc., USA) were inserted into the samples similar to the heating electrodes. The voltage was adjusted to 2 V what level does not induce electrochemical changes. The measured spectra were open-short corrected to eliminate stray inductivity and capacity. Various electrode distances (8, 4, 2 and 1 cm) were applied to determine both sausage and electrode impedance. Sausage impedance (Z_S) was calculated using serial connection of two distributed elements and a resistance (Eq. 1.).

$$Z_S = R + \frac{R_1}{1+(i2\pi f\tau_1)^\psi_1} + \frac{R_2}{1+(i2\pi f\tau_2)^\psi_2} Z_S = R + \frac{R_1}{1+(i2\pi f\tau_1)^\psi_1} + \frac{R_2}{1+(i2\pi f\tau_2)^\psi_2} \quad (1)$$

where R represents resistance, f means measurement frequency, τ means relaxation time, ψ [0,1] is

exponent. According to the model, sausage resistance is R and $(R+R_1+R_2)$ at infinite high and zero frequencies, respectively.

COMSOL® Multiphysics simulation software (version 5.3, COMSOL Inc., USA) was used to perform finite element modeling. Parameter values, such as density and specific heat of ingredients, were estimated according to Choi et al. (1986). Models calculated electromagnetic field and temperature data in sausage samples. Theoretical values were compared to experimental readings.

Experimental data was collected, preprocessed and evaluated in Excel® (Microsoft Inc., USA) and R (R Foundation for Statistical Computing, Austria) software.

Results and discussion

Simulation

Geometry model of sausages was made of a cylinder and two closing semi-spheres. Electrodes of cone shape were inserted at the top of the spherical ends (Fig. 2). Simulations were performed on a workstation of Intel I7-3820 @ 3600 GHz CPU and 64 GB RAM in the laboratory of University of Salerno, Italy.

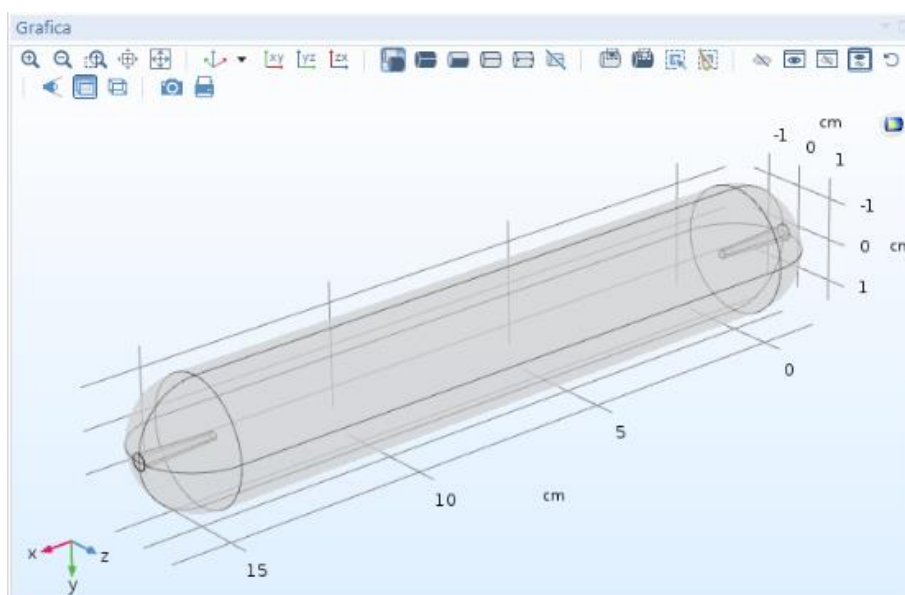


Figure 2. Shape model of sausages in COMSOL 5.3

Shape model was created with cylinder of 2.8 cm and 15 cm length, cone of 0.1–0.2 cm and 1.9 cm length. Simulation was performed using mesh optimized for best spatial resolution consisting of 2650 tetrahedrons, 742 boundary elements and 188 edges. Results were visualized with plots of surface temperature and volumetric temperature distribution (Fig. 3) after 30 s treatment.

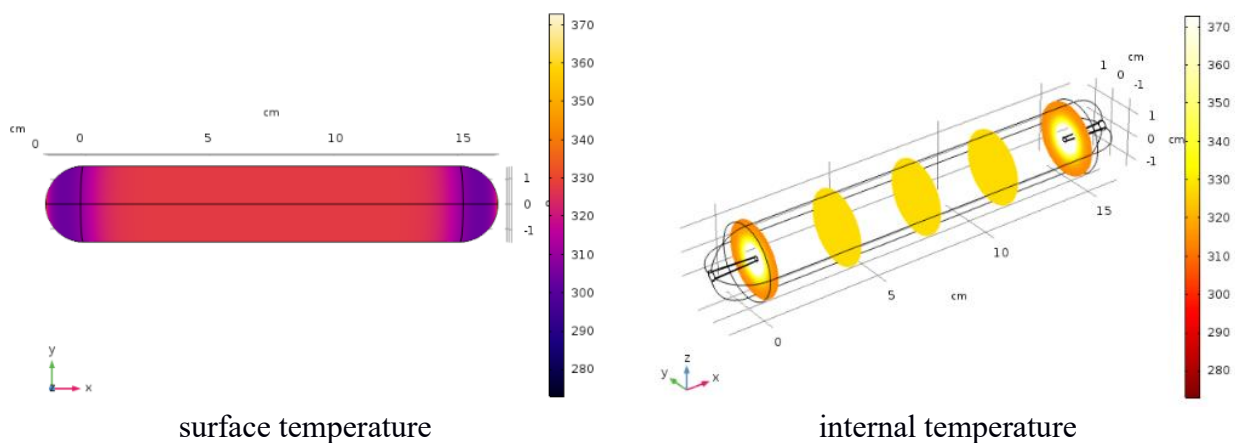


Figure 3. Surface and sliced temperature plots of ohmic heating with 200 V at 30 s

Both surface and internal temperature became homogeneous between electrodes and cold region was observed around electrodes. The ring of coldest region is located symmetrically around the electrodes near surface. The structure is more visible on horizontal slice plot of $z=0$ (Fig. 4). On the other hand, highest temperature region is located closest to electrodes where over processing or burning can occur.

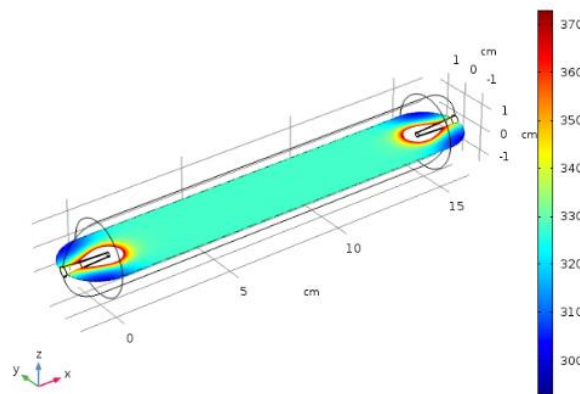


Figure 4. Horizontal slice plot of ohmic heating with 200 V at 30 s

The effect of salt content was found to be significant. Higher salt content was estimated to obtain higher temperature (Fig. 5). According to the calculated temperature distribution volume between electrodes will be warmer but cold region remain on same level. This result is in agreement with literature where pretreatment of meats with salt solution is recommended. Although higher salt content may accelerate treatment, it is less desired due to the changing sensory attributes.

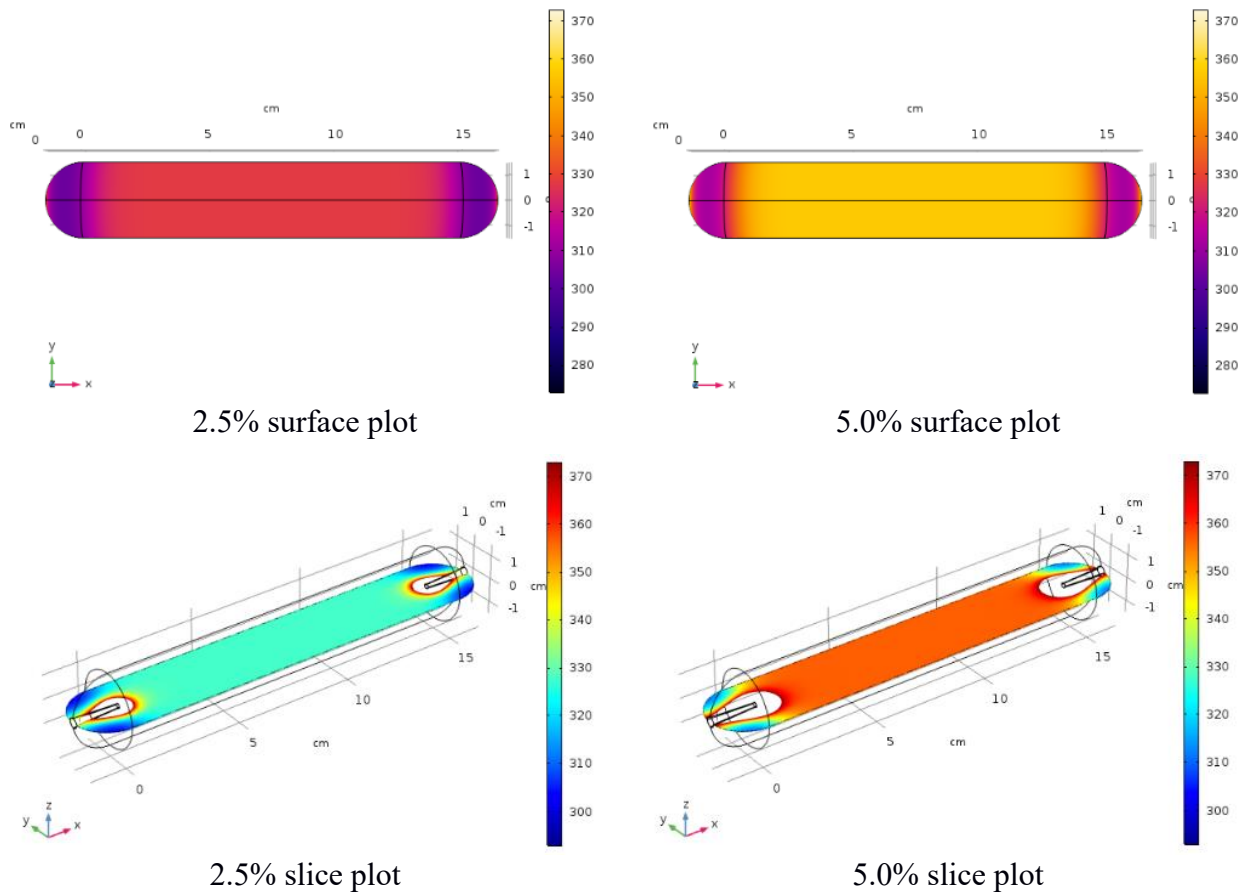


Figure 5. Temperature distribution by salt content with 200 V at 30 s

Dielectric measurement

Investigation of sausage impedance revealed that real part obtained much higher values than imaginary part. This observation suggests that sausage has mainly ohmic impedance with very weak capacitive character. Curve fitting based on impedance model (Eq. 1) identified parameters as they are listed in Table 2. According to the results, electrical conductivity from zero to infinite high frequency is in the range of 0.78 – 1.13 S/m.

Table 2. Parameters of sausage impedance model

	R, Ω	R_1, Ω	τ_1, ms	ψ_1	R_2, Ω	τ_2, ms	ψ_2
Mean	2.82	0.87	0.445	0.98	0.40	0.123	0.324
Deviation	0.558	0.502	0.269	0.028	0.205	0.013	0.291

Ohmic heating experiment

Based on theoretical considerations, ohmic cooking treatment was expected to take 30 – 245 s depending on adjusted voltage. The primary factor affecting ohmic cooking was the applied voltage. It was observed that temperature and current increased parallel at the beginning and current reached the maximum when meat burnt around electrodes. Burnt meat is likely to finish treatment since isolates electrode and prevents current flow. The temperature increased with 60.5, 87.6 and 101.5 °C for 50, 125 and 200 V, respectively. Similar kinetics was observed in case of all levels as it is presented for the initial part (Fig. 6).

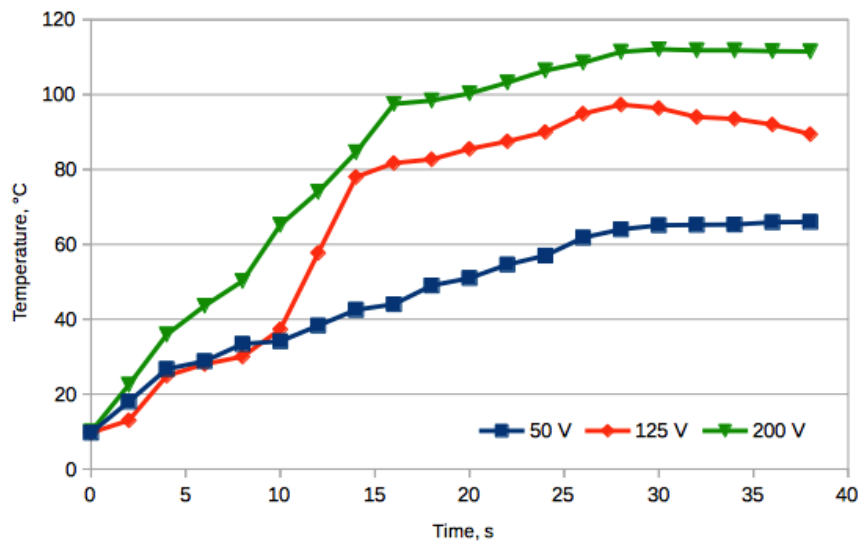


Figure 6. Temperature readings of ohmic heating

Voltage level of 125 V was found to be optimal choice for pork sausage. The level of 50 V was unable to cook samples comparable to traditional method, while 200 V burnt meat quickly and finished treatment. Comparison of current and temperature kinetics revealed that current decreased when increase in temperature did slow down or reached constant value. There was shift between changes in current and temperature data, indicating that both electromagnetic field and internal heat transfer cooked sausages. Measured current increased exponentially at the beginning and continued growing slower, finally dropped rapidly. These three phases were observed in all experiments, using constant voltage.

Experimental readings captured with thermovision supported simulation results regarding cold region and spatial pattern (Fig. 7). Volume between electrodes was heated homogeneously and its cylindrical region was visible on acquired images. The ring of cold region was also found on thermal images close to electrodes. This region has to be cooked with heat transfer and must be considered as the most important in hazard analysis. Since ohmic heating starts treatment inside the sample with current

stream, surface emission captured with IR images is able to analyze its pattern and help optimization. Slight distortion of the expected geometric shape was observed due to the position of electrode within the curved sausage.

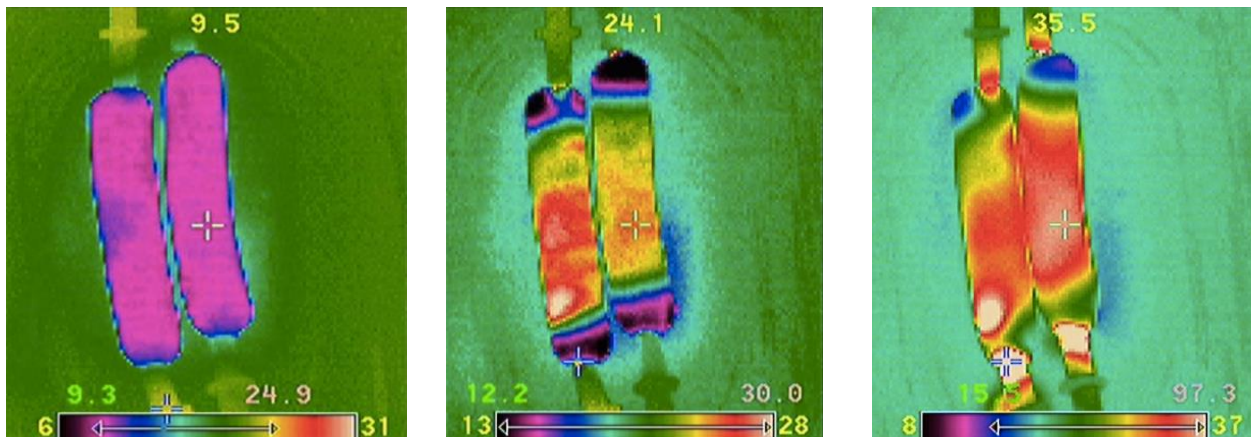


Figure 7. Thermovision images during ohmic cooking with 125 V at 0, 8 and 28 s

Conclusions

Pilot plant was designed and used in order to investigate ohmic heating of Viennese type pork sausages. In contrast to literature, ready to eat food product does not seem to require additional treatment to increase salt content or immersion into salt solution. It could be applied to improve treatment but may change sensory attributes as well. The electricity of 125 V was able to cook sausages rapidly and surface temperature increased with 87.6 °C during experiment. Lower level of 50 V was found to be slower and therefore less practical. On the other hand, high level of 200 V was too rapid and burnt meat around electrodes quickly without useful cooking. Finite element simulation results were in the agreement with experimental readings. Temperature was observed to increase primarily in the cylindrical part between electrodes and the cold point was found on the surface of semi-spheres at the ends. Calculations of treatment time and protocol considering microbial safety shall focus on the heating of this region. Ohmic heating is a promising technology to cook homogeneous foodstuff, such as sausages, rapidly and more economically. Treatment requires optimization in order to cook all regions taking care of microbial safety, control current and voltage to maintain joule heating without burning the product.

Acknowledgements

The Project is supported by the European Union and co-financed by the European Social Fund (grant agreement No. EFOP-3.6.3-VEKOP-16-2017-00005).

References

- Bozkurt, H. & Icier, F. (2010). Ohmic cooking of ground beef: Effects on quality. *Journal of Food Engineering*, 96, p. 481–490
- Cappato, L.P., Ferreira, M.V.S., Guimaraes, J.T., Portela, J.B., Costa, A.L.R., Freitas, M.Q., Cunha, R.L., Oliveira, C.A.F., Mercali, G.D., Marzack, L.D.F. & Cruz, A.G. (2017). Ohmic heating in dairy processing: Relevant aspects for safety and quality. *Trends in Food Science & Technology*, 62, p. 104–112
- Castro, I., Teixeira, J.A., Salengke, S., Sastry, S.K. & Vicente, A.A. (2004). Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics. *Innovative Food Science and Emerging Technology*, 5, p. 27–36
- Jaeger, H., Roth, A., Toepfl, S., Holzhauser T., Engel, K-H., Knorr, D., Vogel, R.F., Bandick, N., Kulling, S., Heinz, V. & Steinberg, P. (2016). Opinion on the use of ohmic heating for the treatment of foods. *Trends in Food Science & Technology*, 55, p. 84–97
- Jones, D.A., Lelyveld, T.P., Mavrofidis, S.D., Kingman, S.W. & Miles, N.J. (2002). Microwave heating applications in environmental engineering – a review. *Resources, Conservation and Recycling*, 34, p. 75–90
- Lima, M. & Sastry, S.K. (1999). The effects of ohmic heating frequency on hot-air drying rate and juice yield. *Journal of Food Engineering*, 41, p. 115–119
- Sakr, M. & Liu, S. (2014). A comprehensive review on applications of ohmic heating (OH). *Renewable and Sustainable Energy Reviews*, 39, p. 262–269
- Sengun, I.Y., Turp, G.Y., Icier, F., Kendirci P. & Kor, G. (2014). Effects of ohmic heating for pre-cooking of meatballs on some quality and safety attributes. *LWT - Food Science and Technology*, 55(1), p. 232–239
- Zell, M., Lyng, J.G., Cronin, D.A. & Morgan, D.J. (2009). Ohmic cooking of whole beef muscle – Optimisation of meat preparation. *Meat Science*, 81, p. 693–698
- Zell, M., Lyng, J.G., Cronin, D.A. & Morgan D.J. (2010). Ohmic cooking of whole beef muscle – Evaluation of the impact of a novel rapid ohmic cooking method on product quality. *Meat Science*, 86, p. 258–263.